DOCUMENT RESUME

ED 464 482 EF 006 117

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TITLE	An Approach to Management of Critical Indoor Air Problems in School Buildings.
INSTITUTION	National Inst. of Environmental Health Sciences (NIH), Washington, DC.
SPONS AGENCY	Ministry of Education, Helsinki (Finland).
ISSN	ISSN-0091-6765
PUB DATE	1999-06-00
NOTE	8p.; Based on a presentation at the International Conference on Indoor Mold and Children (Alexandria, VA, April 21-24, 1998).
AVAILABLE FROM	For full text: http://ehpnet1.niehs.nih.gov/docs/1999/suppl-3/toc.html.
PUB TYPE	Journal Articles (080) -- Speeches/Meeting Papers (150)
JOURNAL CIT	Environmental Health Perspectives; v107 suppl 3 pp509-514 Jun 1999
EDRS PRICE	MF01/PC01 Plus Postage.
DESCRIPTORS	Air Pollution; Asthma; Child Health; *Foreign Countries; *Hazardous Materials; High Schools; *School Buildings; School Safety; Ventilation
IDENTIFIERS	*Indoor Air Quality; *Molds (Biology)

ABSTRACT

This study was conducted in a school center in Finland that had been the focus of intense public concern over 2 years because of suspected mold and health problems. Because several attempts to find solutions to the problem within the community were not satisfactory, outside specialists were needed for support in solving the problem. The study group consisted of experts in civil engineering, indoor mycology, and epidemiology. The studies were conducted in close cooperation with the city administration. Structures at risk were opened, moisture and temperature were measured, and the causes of damage were analyzed. Microbial samples were taken from the air, surfaces, and materials. Health questionnaires were sent to the school children and personnel. Information on the measurements and their results was released regularly to school employees, students and their parents, and to the media. Repairs were designed on the basis of this information. Moisture damage was caused mainly by difficult moisture conditions at the building site, poor ventilation, and water leaks. Fungal genera typical to buildings with mold problems were collected from the indoor air and surfaces of the school buildings. Where moisture-prone structures were identified and visible signs of damage or elevated moisture content were recorded, the numbers of microbes also were high; thus microbial results from material samples supported the conclusions made in the structural studies. Several irritative and recurrent symptoms were common among the upper secondary and high school students. The prevalence of asthma was high (13 percent) among the upper secondary school students. During the last 4 years, the incidence of asthma was three-fold that of the previous 4-year period. (Contains 18 references.) (Author/EV)

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Environmental Health Perspectives, Volume 7, Supplement 3, June 1999

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An Approach to Management of Critical Indoor Air Problems in School Buildings

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This study was conducted in a school center that had been the focus of intense public concern over 2 years because of suspected mold and health problems. Because several attempts to find solutions to the problem within the community were not satisfactory, outside specialists were needed for support in solving the problem. The study group consisted of experts in civil engineering, indoor mycology, and epidemiology. The studies were conducted in close cooperation with the city administration. Structures at risk were opened, moisture and temperature were measured, and the causes of damage were analyzed. Microbial samples were taken from the air, surfaces, and materials. Health questionnaires were sent to the schoolchildren and personnel. Information on the measurements and their results was released regularly to school employees, students and their parents, and to the media. Repairs were designed on the basis of this information. Moisture damage was caused mainly by difficult moisture conditions at the building site, poor ventilation, and water leaks. Fungal genera (concentrations <200 colony-forming units (cfu)/m^3, <3000 cfu/cm^2) typical to buildings with mold problems (e.g., *Aspergillus versicolor, Eurotium*) were collected from the indoor air and surfaces of the school buildings. Where moisture-prone structures were identified and visible signs of damage or elevated moisture content were recorded, the numbers of microbes also were high; thus microbial results from material samples supported the conclusions made in the structural studies. Several irritative and recurrent symptoms were common among the upper secondary and high school students. The prevalence of asthma was high (13%) among the upper secondary school students. During the last 4 years, the incidence of asthma was 3-fold that of the previous 4-year period. *Key words*: asthma, health effects, moisture damages, mold, questionnaire, respiratory symptoms. — *Environ Health Perspect* 107(suppl 3):509–514 (1999). *http://ehpnet1.niehs.nih.gov/docs/1999/suppl-3/509-514haverinen/abstract.html*

Indoor air problems caused by the moisture and mold occur not only in residential but also in public buildings (*1*). Microbial growth and building moisture is associated with adverse health effects such as respiratory symptoms and the increased prevalence of respiratory infections (*2*). In many cases, however, there is not sufficient local experience to recognize a building-associated disease, to determine the documentation needed for correct conclusions, and to manage the overall case. This study concerns a school center in a small town in southern Finland, where the occupants had symptoms associated with the buildings. As experience with indoor air problems was insufficient among the health authorities, the town administration turned to a group of outside experts. The aims of the study were to assess the moisture and microbial status of the school buildings and the health situation of the school occupants, and to establish a strategy to deal with this type of problem.

We report an approach to managing indoor air problems associated with moisture and mold in a practical situation. The investigations and analyses required to obtain the necessary information, as well as the essential findings, are briefly described.

Material and Methods

The school center contained three buildings. The upper secondary and high schools were located mainly in building complex A, called stone school, which has three parts: part A1 (built in 1954), part A2 (built in 1951), and part A3 (built in 1961). Building B, the elementary school, is a brick building built in 1955. In addition, the upper secondary and high schools use facilities from building C—the wooden school, a log building constructed in 1888.

The study included structural, microbial, and health effects studies. Each part of the study was supervised by experts in the field. All studies were done in close cooperation with the town administration. The studies advanced hierarchically and the results of each step were discussed in meetings. The overall design of the study is presented in Figure 1.

Structural Survey

This section of the study analyzes the moisture status of the structures and the causes of the moisture accumulation. On the basis of the results of the investigations, advice was given on the removal and replacement of the damaged structures and improving the moisture capacity, i.e., the resistance of the structures against moisture. The project started in June 1996, after the schools were closed for summer vacation, and the repairs were to be completed before the new semester started in August of the same year. Because of the schedule, the study was conducted parallel with the construction work.

All available building documents, e.g., drawings, structural designs, and information about repair history of the buildings, were collected and the buildings were first examined visually (*3*). The most serious problems were registered in the base floors of the buildings. For on-site investigations, 20-mm holes were drilled throughout ground slab at 15 sites and through the wall structures at 2 sites (Figure 2). Building material layers and thickness were observed from cuttings and drill ability. If the drilling was successful, the holes were obstructed and the conditions were allowed to stabilize before moisture and temperature was measured. A bar was driven into the holes until the resistance became too great, to define soil type and moisture condition. To obtain more information, the structures were later opened (e.g., areas of approximately 0.2–1 m^2 were dismantled at 10 sites) (Figure 2). The ventilation in the

This article is based on a presentation at the International Conference on Indoor Mold and Children held 21–24 April 1998 in Alexandria, Virginia.

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The authors thank U. Kolehmainen, M. Vahteristo, and J. Chelelgo for their excellent technical assistance, and the students and teachers of the school center for cooperation during the study. The study was supported financially by the Finnish Ministry of Education.

Received 3 September 1998; accepted 2 February 1999.

crawl spaces under the ground floors was tested with a thermohygrograph.

Microbial Study

Microbial samples were taken to locate the sources of microbial growth and to characterize the fungal genera of the buildings for exposure assessment (4). Basic data from the microbiologic indoor air quality were obtained before construction started. Airborne samples were collected with six-stage impactors. Surface samples were collected by swabs, diluted, and plated onto culture medium. Material samples were taken from various layers of the moisture-prone structures (such as surfaces, insulation, frames) when they were dismantled for structure investigations. One to five grams of material was used for extraction of the microbes, and the suspension was plated onto culture medium.

Two percent malt extract and dichloranglyserol-18 agars were used for mesophilic fungi, and tryptone glucose yeast agar was used for bacteria. After 7 days of incubation at 25°C, the colonies were counted and the fungal flora was determined. The bacterial samples were incubated at 20°C for 14 days. Concentrations of viable fungi were regarded as elevated according to the guidelines given by Finnish Ministry of Social Affairs and Health (5): air samples > 100 colony-forming units (cfu)/m^3 if the finding was supported by the unusual genera, surface samples > 1,000 cfu/cm^2, and material samples > 10,000 cfu/g. The fungal colonies were identified morphologically. The occurrence of the genera, which indicated moisture as well as an unusual rank order of the genera (4,6), was recorded.

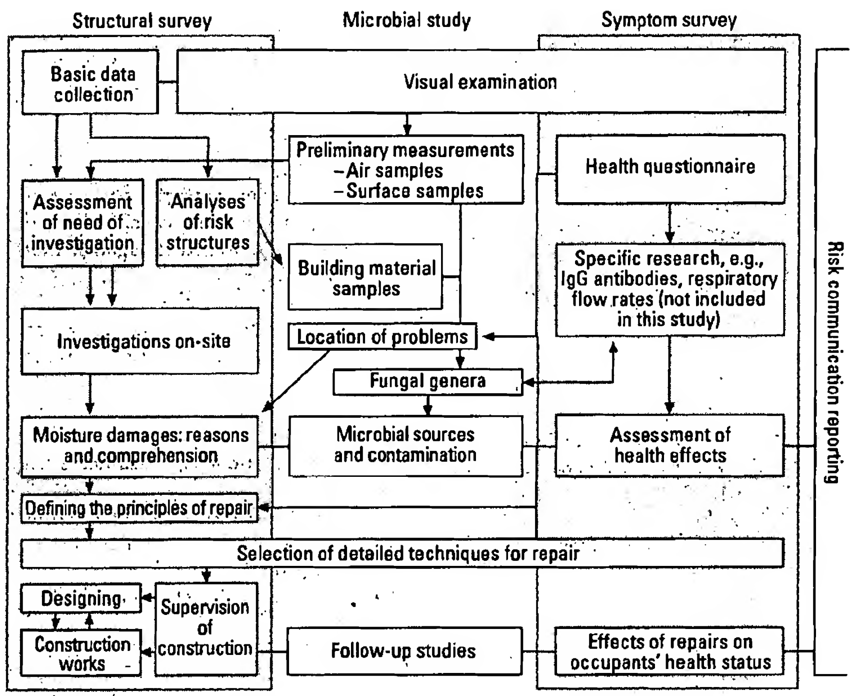

Figure 1. Flow chart of the study design.

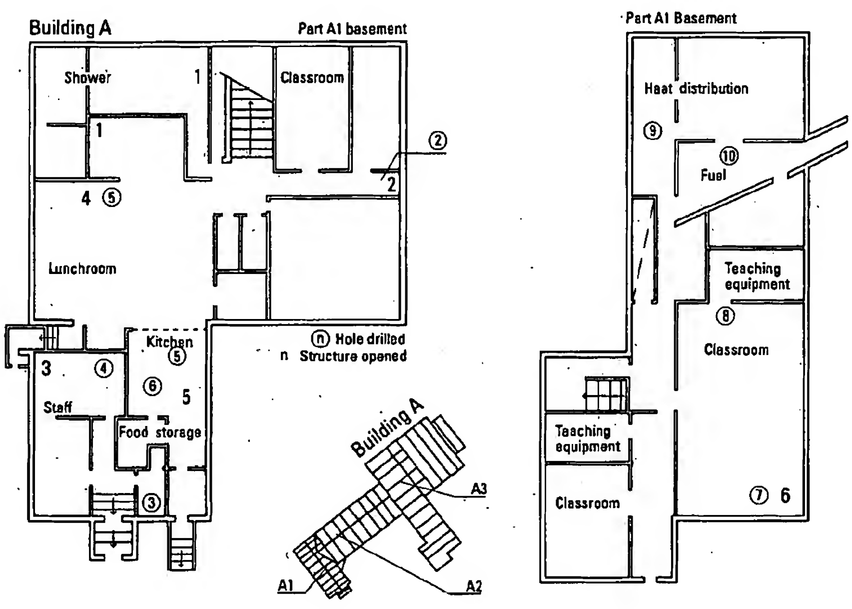

Figure 2. Site map of structural measures. See Table 1.

Surveyors were advised to wear respiration filters and protective clothing during those stages of the investigations when mold or dusty materials were handled. Problematic rooms were not used and were isolated before they were repaired to avoid air change between other facilities. Some repairs were performed using dust techniques similar to those used in asbestos abatement. Recommendations were made for cleaning of the rooms (working methods, chemical types, etc.) after the removal of materials contaminated by microbes. These included wiping all surfaces and disinfecting materials prone to contamination, e.g., chlorine treatment of concrete (7). In addition, to protect wooden parts that could not be replaced, disinfection with boron substances was recommended.

Symptom Survey

Questionnaires on respiratory disorders and other irritative and general symptoms were delivered to the occupants of the buildings before any technical investigations began. The questionnaires for the students were delivered by the teachers of each school level. The upper secondary and high school students filled in the questionnaires themselves (with help from their parents if needed). The questionnaires of the elementary school students were completed by the parents together with the child. The students returned the questionnaires to the schools, where they were

collected by the teacher. Questionnaires for school personnel were sent to their homes with return instructions and prepaid envelopes. About 1 month later, letters of inquiry were sent to the homes of both students and personnel who had not returned the questionnaire.

The questionnaires used were developed on the basis of earlier studies on air pollution and respiratory health (*8,9*); they had been used for mold-related designs in several studies (*10,11*). The questionnaire for students included 44 questions on respiratory and general health, and allergies of the subject; 12 questions on housing and sociodemographics of the families; and 16 questions about the school. Asthma was included: Has a doctor ever said that you have/your child has asthma? (No/Yes, diagnosed year 19__.) The questionnaire for the employees was more specific and consisted of a section on working conditions with 31 questions and a section on health information with 91 questions. In the section on working conditions, there were questions about the work, employee position and length of service, working motivation and atmosphere, and causes and sites of inconveniences experienced by the work. The section on health information documented symptoms and diseases such as respiratory infections and factors that were related to them according to the respondent. General information, such as housing, living habits (smoking, free-time activities), and education, was also recorded in this section of the employee questionnaire.

The extent of symptoms of the students and personnel working in buildings A and C were compared with those in building B, which was assumed to be a nondamaged reference building. The data were analyzed with the SPSS program (SPSS 6.0 for Windows) by using χ^2 and *t*-tests, adjusting for age, sex, smoking, and atopy with logistic regression model (*12*). The accepted level of statistical significance was $p < 0.05$.

Risk Communication

Because suspected indoor air problems had hitherto remained unsolved and caused public concern for over 2 years, there was little confidence among school personnel, parents, and the general public that the authorities would find a solution. Special attention was paid to communication in overcoming this problem. During the study, information about the investigations and the results was released to school employees, students and their parents, the general public, and the media.

Results

Causes and Comprehension of Moisture Damages

One of the main reasons for problems in the wooden school (C) was poor ventilation of the base floor structures. During the 1970s, the ventilation holes had been obstructed in an attempt to save energy. The ground was graded toward the building, which directed the flow of rainwater under the building. Depart from the drawings of the buildings, the surface of the ground was partly level with the wooden frame. Some incorrect construction methods are used. The building lacked mechanical ventilation as well. These conditions led to the growth of rot fungi, causing decay of the base floor structures and lower wall logs, and creating a risk for the collapse of the floor structures (*13*). After a fire in 1984, large areas had been covered with water. High concentrations of fungi and bacteria were found in upper floor insulation materials, indicating that some wet materials may have been left in the building. All contaminated materials were destroyed at the time of the study at this phase.

Various structure layers were observed from different sites in the stone school (A) and assumed to be results of earlier repairs. In general, structures could be categorized into two types: structures with layers of wooden materials and structures consisting mainly of concrete materials (Figure 3). Results from the structural measurements in the building are presented in Table 1. Moisture conditions in the site were problematic. The base floor was built mostly on a thick level of capillary clay, partly without

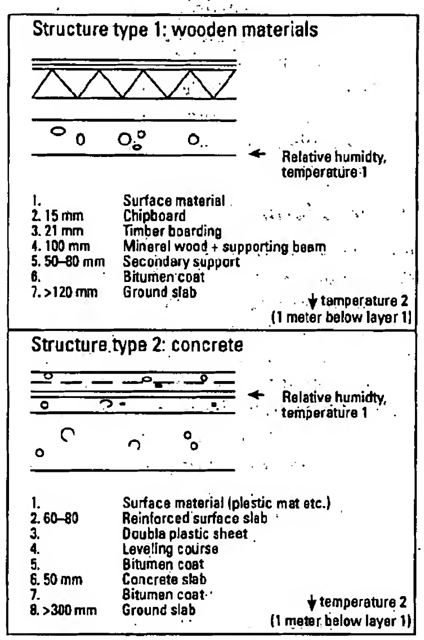

Figure 3. Examples of base floor structures in the stone school (A), categorized as wooden structures (type 1) and concrete structures (type 2). See Table 1.

Table 1. Results of the structural measures.

Drill hole number	Structure opening number	Relative humidty (%)	Room temperature (°C)	Temperature 1[a] (°C)	Temperature 2[a] (°C)	Type of the structure[a]	Microbial sample taken	Microbial growth recorded
–	1	–	–	–	–	2	Yes	Yes[b]
1	–	90	19	–	–	2	Yes	No
2	2	90	19	17	16[c]	1	Yes	No
3	–	88	19	15	–	1	Yes	No
4	3	[d]	–	–	–	1	Yes	Yes
5	4	88	19	20	–	2	No	–
6	5	80	19	–	–	2	Yes	No
6	–	20	–	–	1	Yes	Yes	
7	–	93	20	16	13[e]	1	No	–
8	–	94	20	19	17[c]	2	No	–
9	–	54	20	18	14[c]	2	No	–
10	–	94	20	19	16[c]	2	No	–

[a]According to Figure 3. [b]Microbial growth recorded under the topping slab. [c]Water does not flow below the ground slab. [d]Wood sample moisture content 12% by weight. [e]Water flows below the ground slab.

capillary break. A groundwater monitoring tube showed that the groundwater was at the level of the concrete slab lower surface. Before the underdrain, rainwater sewer, and cellar walls outside the water barrier were built in the fall of 1995 as part of the repair process, surface water could seep under the building. Changes in this type of soil occur slowly; but it may also be impossible to stop the water penetration. All wooden structures (structure type 1) of the floor of the basement store had to be replaced by structures with better moisture resistance (*14*) and with surfaces through which possible moisture would evaporate.

In the elementary school (B) basement classroom, damaged floor structures were observed. Although the measurements did not indicate unusual moisture, the structure was opened. Under the chipboard layer an area of approximately 1 square meter was filled with water from a leak in the plumbing.

Table 2. Occurrence of *Aspergillus versicolor* in various samples taken from school buildings.

	Concentration of *A. versicolor* in risk facilities and structures	Concentration of *A. versicolor* in reference samples	
Building A			
Indoor air samples	0–180 cfu /m^3	Outdoor air	–
Surface samples	0–2,230 cfu/cm^2	Reference surfaces	
Material samples	0–10,500 cfu/g		
Building B			
Indoor air samples	–	Outdoor air	–
Surface samples	–	Reference surfaces	
Material samples	–		
Building C			
Indoor air samples	0–10 cfu/m^3	Outdoor air	–
Material samples	0–222,000 cfu/g		

Table 3. Concentrations of viable fungi on building materials from some risk structures.

Samples	Total fungi range (cfu/g)	Total bacteria range (cfu/g)
1—Building A, base floor, wooden structures (type 1)	50–11,400	270–2,160
2—Building A, base floor, concrete structures (type 2)	0–150	0–950
3—Building B, classroom base floor, chipboard	772,000	585,000
4—Building C, floor and lower wall log structures	0–527,000	180–830,000

Microbial Status

In the wooden school (C), rot fungi damages were obvious, as assessed by the deterioration of wooden structures. Airborne concentrations of viable fungi in the stone and elementary schools were at the level normally found in school buildings (*15*). However, small concentrations of fungal genera typical to buildings with mold problems (*Aspergillus versicolor, Aspergillus fumigatus, Eurotium*) were found in the stone school's (A) air samples (*6*). (Data not shown.)

In some surface samples of the stone school (A), concentrations were unusually high, and the genera present, e.g. *A. versicolor*, indicated problems with moisture and mold (*6*). *A. versicolor*, which is often associated with damp buildings, was the most common genus detected in various damaged samples. The concentrations of *A. versicolor* are therefore presented here as an example (Table 2).

In general, microbial results from material samples supported the conclusions made in the structural studies (Table 3). For example, high concentrations of fungi detected from the materials from wooden floor structures of the stone school (A) (sample 1) indicated a high moisture content and the decision was made to remove the structures. Microbial concentrations in the concrete floor structures were relatively small (sample 2). Sample 3 from the classroom in the elementary school (B) had high concentrations of fungi. In addition to rot fungi, mold was also found in the wooden school (C) structures (sample 4).

Health Effects

The completed questionnaire was returned by 171 (81%) elementary school children, 174 (91%) upper secondary school students, and 109 (89%) high school students. Forty teachers (91%; 15 elementary school teachers, 18 upper secondary school teachers, and 7 high school teachers) and 15 (94%) other personnel returned the questionnaire.

Some results are reported in Table 4. Several irritative and nonspecific symptoms such as nasal congestion, rhinitis, phlegm, shortness of breath, eye irritation, hoarseness, and fatigue, during the previous year of the study, were significantly more common among the upper secondary and high school students than among the elementary school children. After adjusting for age, sex, smoking, and atopy, the observed differences among the student groups remained significant in nasal congestion, rhinitis, phlegm, hoarseness, and fatigue (odds ratios not shown). The exposed students also had had more long-term and repetitive flu, cough, and eye symptoms. Asthma symptoms were common among upper secondary and high school students.

The prevalence of asthma among the upper secondary school students was high (13%) compared to recently reported average prevalence of asthma among this age group (4–7% in different in regions of Finland) (*16*). During the previous 4 years, 18 new cases of asthma were diagnosed, whereas in earlier 4-year periods 4–6 cases were diagnosed annually (Table 4). Use of health services and medication because of asthma was not any higher in this group than among youth of the same age on average.

Discussion

The types of moisture damages can be divided into four categories:

- Incorrect methods of construction, maintenance, or repair, which are often easily found and solved, can cause damage. Most of the problems in the wooden school (C) belonged to this group.
- Damage in the stone school (A) was caused by moisture penetrating from the ground. Resolution of this type of moisture damage is difficult and can be expensive.
- Moisture load from ordinary use was high in some facilities. The kitchens of the school center belonged to this group. Water was poured onto the floors on a daily basis while washing surfaces, and large-scale cooking appliances produced steam. Ventilation was not sufficient to remove the humidity. This type of moisture load creates a situation with high risk of damage.
- The water used in firefighting and water leaks were examples of cases in which even a well-functioning structure became moldy because of an external factor. The seasonal climate variation in Finland may also cause moist conditions in structures that are suitable for microbial growth.

Success in making correct conclusions on the basis of the structural survey depends on

Table 4. Comparison of some recurrent symptoms, asthma symptoms, and allergic diseases in the students in elementary, upper secondary, and high schools and reported asthma detection years among the students of the school center.

	Elementary school students,[a] n (%)	Upper secondary school students,[b] n (%)	High school students,[b] n (%)	p
Nasal congestion	89 (48)	125 (74)	79 (73)	***
Rhinitis	92 (50)	130 (77)	76 (70)	***
Phlegm	37 (20)	69 (40)	36 (33)	**
Shortness of breath	16 (9)	34 (20)	17 (16)	*
Eye irritation	30 (16)	56 (33)	39 (36)	***
Hoarseness	40 (22)	74 (44)	32 (30)	***
Fatigue	48 (26)	135 (79)	85 (78)	***
Difficulties in exhalation				
Occasionally	27 (15)	60 (35)	42 (39)	***
At school	1 (1)	21 (12)	10 (9)	***
Wheezing				
Occasionally	29 (16)	69 (41)	41 (38)	***
At school	1 (1)	9 (5)	2 (2)	*
Allergic rhinitis	22 (24)	54 (32)	36 (33)	
Allergic conjunctivitis	26 (14)	27 (16)	20 (18)	
Asthma	19 (5)	22 (13)	8 (7)	*

Year	Number of students diagnosed with asthma
1980–1984	6
1985–1988	4
1989–1992	4
1993–1996	18

[a]Use facilities from building B. [b]Use facilities from buildings A and C. *$p < 0.05$. **$p < 0.01$; ***$p < 0.001$ calculated from crude rates.

the surveyor's expertise. In the case of moisture problems, knowledge of the structure's moisture physics is essential. Buildings must be examined systematically, and observations may need support from measurements and other study methods. It is important to realize that even if damage is small from a structural point of view, it may still lead to microbial growth and cause adverse health effects. The mitigation of mold problems is therefore multidimensional.

In the microbial study, air and surface samples provided basic data for the structural survey and helped locate the moisture sites. The conclusions made on the basis of the structural survey were supported by the microbiological results of the material samples, which verified the presence of microbial growth in the sites considered high risk for moisture damage from a technical point of view. It was informative to carry out these two studies in parallel. Microbial growth in structures is caused by excessive moisture. By understanding the structure's moisture physics and microbiology, the origin of the problem often can be found and removed.

Microbial results vary with time, place, circumstances of sampling, and methods used, and the determinants of total exposure to microbes are poorly known so far. Viable or culturable microorganisms comprise 1–10% of the total number of microbial cells; on the basis of our present understanding, the numbers and genera of viable microorganisms reflect the microbial status of the building and are satisfactory surrogates of the exposure once the sampling has been properly focused (*4,6,15*). A microbial or structural study alone may not lead to independent conclusions, but both are needed in evaluating the situation.

Information obtained from the questionnaire about the facilities where the users had experienced problems helped to identify the structural problems. The unusually high prevalence of respiratory symptoms, their association with school buildings A and C, and the increased incidence of asthma indicated that a comprehensive investigation of the condition of the buildings was necessary.

The prevalence of asthma among the upper secondary school students was twice that of the general population prevalence of asthma among teenagers (*8,16*). Among the students who returned the questionnaire, in the previous 4 years, the asthma incidence was 3-fold as compared to earlier 4-year periods. Use of health services and medication because of asthma was not higher in these teenagers than in other teenagers on average, indicating relatively moderate or early-phase illnesses.

Some moisture faults were also found in the elementary school (B), which was originally assumed to be a nondamaged reference building and was therefore studied only briefly. Naturally, the minor damages found may also have caused exposure and symptoms of the occupants. However, significant differences were found among the health status of the occupants of buildings A and C, compared to those among occupants of this building (B). Had the reference building been undamaged, the observed differences in health status of the student groups may have been even bigger. On the other hand, the degree of the damage depends on several variables such as age, use, maintenance, and repair of the building. Thus, a completely undamaged building may be as abstract a concept as is a totally healthy human being.

The exposure in home environment may play a role in the development of respiratory symptoms and asthma, but in this study it was not possible to assess the domestic situation of each participant. It could be assumed that the possible exposure in the home environment was equally distributed among the occupants of the different buildings A, B, and C.

The reporting of symptoms associated with the buildings may have increased as a result of common awareness and publicity about the study. Information collected in self-administered questionnaires is not always as valid as that collected in clinical studies (*17,18*). The diagnoses of asthma were made by a physician and can be regarded as objective findings. Symptoms associated with mold exposure are otherwise nonspecific and difficult to measure. On the other hand, a questionnaire study is easy to carry out and cost effective, and provides direct information from the occupants.

Special attention was paid to the communication with the occupants of the buildings during the study. Releasing information about the purpose of the studies, the measurements, and their results to the employees, authorities, schoolchildren, parents, and the media helped to open the situation to constructive discussion. Our experience confirmed the importance of public meetings to keep the atmosphere open.

Although the condition of residential buildings is ultimately the owner's responsibility, the distribution of risk is more complicated in public buildings. Situations can result in which the responsibility is not clear but shared among different parties involved. To remedy this kind of situation, it may be necessary to use outside consultants.

The overall purpose of the study was to find a useful management strategy to solve the critical indoor air situation. It was focused not only on supporting the repair of damages but also on carefully analyzing the original cause of the problem to understand the effects. Although it was not possible for each part of the study to cover the problem in its entirety, the different parts complemented one another. To connect the studies in order to construct a systems approach and to draw conclusions for use by the town administration, it was important to combine broad expertise in each part and link them by effective cooperation.

Follow-up studies will be conducted to analyze construction solutions and their effects on moisture resistance in the structure. A microbial exposure follow-up will be done, and the questionnaire study will be repeated after the repairs are completed. The follow-up study will bring further information on the suggested connection between exposure and health findings. Thus it will be possible to assess the effect of elimination of the exposure on the decrease of the illness.

Conclusions

In buildings A and C, several serious moisture problems were identified. The conclusions based on the structural survey were supported by the results of the microbial study, as the sites of moisture damage proved to be sources of unusual microbial growth. Respiratory symptoms and general symptoms were more common among the students occupying these buildings. Each part of the study was needed in order to analyze and link together the reason for the moisture damage, the microbial status of the buildings, and the health disorders of the occupants. The multidisciplinary approach appeared to be a fruitful way to solve a critical situation such as this.

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